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AUTHOR	Chin, Christine
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ABSTRACT

The purposes of this study were to: (1) identify the types of questions that students ask during science learning; (2) explicate the role of students' questions in the knowledge construction process; (3) investigate the relationship between students' questions and approaches to learning; and (4) discuss some emergent issues related to student questioning. Six eighth grade students were observed during class activities and interviewed before and after instruction about related science concepts. Students' questions included basic information questions that were typical of a surface learning approach, and wonderment questions that were indicative of a deep approach. Unlike wonderment questions that stimulated students to hypothesize, predict, thought-experiment, and generate explanations, basic information questions generated little productive discussion. Problem-solving activities elicited more and a wider range of wonderment questions than teacher-directed activities. Although the students did not always ask wonderment questions spontaneously, they were able to generate such questions when prompted to do so. (Contains 2 tables and 41 references.) (Author/SLD)

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Christine Chin
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Abstract: The purpose of this study was to (a) identify the types of questions that students ask during science learning, (b) explicate the role of students' questions in the knowledge construction process, (c) investigate the relationship between students' questions and approaches to learning, and (d) discuss some emergent issues related to student questioning. Six Grade 8 students were observed during class activities, and interviewed before and after instruction about related science concepts. Students' questions included basic information questions which were typical of a surface learning approach, and wonderment questions which were indicative of a deep approach. Unlike wonderment questions which stimulated the students to hypothesise, predict, thought-experiment and generate explanations, basic information questions generated little productive discussion. Problem-solving activities elicited more and a wider range of wonderment questions than teacher-directed activities. Although the students did not always ask wonderment questions spontaneously, they were able to generate such questions when prompted to do so.

Questioning is an integral part of scientific inquiry and the learning process. Students' questions can reveal much about the quality of students' thinking and conceptual understanding (Watts and Alsop 1995, White and Gunstone 1992, Woodward 1992), their alternative frameworks and confusion about various concepts (Maskill and Pedrosa de Jesus 1997), their reasoning (Donaldson 1978), and what they want to know (Elstgeest 1985). Student questioning, particularly at the higher cognitive levels, is also an essential aspect of problem-solving (Pizzini and Shepardson 1991, Zoller 1987).

Self-questioning is also considered to be a metacognitive activity (Wong 1985) and is consistent with the view of generative learning (Osborne and Wittrock 1983, 1985) as learners try to reconcile their prior knowledge and new information in their attempts to make sense of these ideas. Despite the educational value of students' questions, Dillon (1988) found that students asked remarkably few questions, and even fewer in search of knowledge. Few students spontaneously ask high quality thinking questions (White and Gunstone 1992 p. 170), and low levels of questioning and explanation on the part of students have been found to be correlated with lower achievement (Tisher 1977).

Most of the earlier research on student-generated questions focused on students' reading comprehension of text-based questions (e.g. Koch and Eckstein 1991, Pearson 1991) with less research on non-text-based questions. For example, Koch and Eckstein (1991) found that there was improvement in college physics students' reading comprehension when they were taught the skill of formulating questions on textual material. Scardamalia and Bereiter (1992) found that non-text, knowledge-based questions which reflected things that students genuinely wondered about in an effort to make sense of the world, were of a higher order than text-based questions. These questions were significantly superior in their potential contribution to knowledge, in their focus on explanations and causes instead of facts, and in requiring more integration of complex and divergent information.

More recent studies on student-generated questions have focused on the nature of these questions (Watts and Alsop 1995, Watts, Gould and Alsop 1997), the characteristics and influence of students' questions on investigative tasks (Keys 1998), the use of students' questions as indicators of their learning problems (Maskill and Pedrosa de Jesus 1997) and as an alternative evaluation tool (Dori and Herscovitz 1999), and the difficulty that students have in asking questions about abstract concepts (Olsher and Dreyfus 1999). Watts and Alsop (1995) found that students' questions were diagnostic of the state of students' thinking, revealed their frames of reference and unorthodox understanding of science, and were indicative of the routes through which students were seeking understanding. Watts, Gould, and Alsop (1997) discussed three categories of students' questions which were seen to illuminate distinct periods in the process of conceptual change: consolidation questions where students attempted to confirm explanations and consolidate understanding of new ideas in science; exploration questions where they sought to expand knowledge and test constructs; and elaboration questions where students attempted to examine claims and counterclaims, reconcile different understandings, resolve conflicts, test circumstances, track in and around the ideas and their consequences.

Keys (1998) found that when grade 6 students worked in groups to generate their own questions for open-ended science investigations, they mainly varied the teacher-directed activity by essentially repeating the activity but changing one or more of the variables, or invented questions from their own imaginations based on their ideas from previous science lessons and personal experiences from everyday life. Students' questions determined the depth and breadth of the concepts to be learnt, the scientific processes to be used, and the cognitive difficulty of the investigation tasks. Allowing students to generate their own investigation questions stimulated curiosity and encouraged profound thinking about relationships among questions, tests, evidence, and conclusions.

In the study by Maskill and Pedrosa de Jesus (1997), the teacher stopped the lessons from time to time and requested the students to write down any questions they wished about problems or difficulties they were having. The questions were a good source of information about each specific moment of the lesson and provided the teacher with a great deal of information with which to organise future teaching according to the students' needs. In the study by Dori and Herscovitz (1999), 10th grade science students posed questions while practising a variety of learning activities. The students' question-posing capability was then evaluated by using pre- and post-test questionnaires where the students were presented with a case study and asked to compose as many questions as they could about the case they had read. There was a significant increase in students' question-posing capability (as indicated by the total number, orientation, and complexity of questions). The findings also showed that question-posing capability can be used as a means of evaluating higher-order thinking.

Olsher and Dreyfus (1999) found that the number of questions that junior high school students could ask about abstract concepts and 'black box' molecular biochemical processes was limited compared to questions pertaining to the clarification of terms or which referred to the human and social aspects of the uses of biotechnologies. However, the students were able to ask questions relevant to the processes at later stages of the lesson after some intense scaffolding.

The findings from the above-mentioned studies indicate that there is substantial educational potential in student-generated questions in directing students' inquiry and guiding

their construction of knowledge. Most earlier studies (such as those concerned with text-based questioning) adopted a process-product approach, typically comparing the effects of an intervention with a comparison group and focusing on student achievement. More recent studies, however, have used a sociolinguistic approach which emphasises the interactional nature of classroom discourse and social contexts. Carlsen (1991) suggested that three features of questions (viz. context, content, and the responses and reactions by speakers) can be considered in sociolinguistic research on classroom questioning which can address the dynamics and active construction of meaning that the process-product paradigm is unable to consider.

Also, previous studies focused primarily on questions produced individually, and in written form. Little research has been done to investigate how students' questions relate to the construction of their conceptual knowledge, and how the use of such questions figures into educational discourse, in a naturalistic setting. It is thus of interest to study how questions produced both individually and in a group setting, scaffold and interact in students' collaborative inquiry and the process of knowledge construction. Accordingly, the purpose of this study was to (a) identify the types of questions that students ask during science learning, (b) explicate the role of students' questions in the knowledge construction process, particularly in educational discourse in small-group collaborative settings, (c) investigate the relationship between students' questions and approaches to learning, and (d) discuss some emergent issues related to student questioning.

Design and Methods

A case study approach (Merriam 1988, Stake 1995) of six Grade 8 target students from a school in a U.S. mid-western university town was used to obtain rich, in-depth data from classroom discourse in small-group settings. The students represented learners of different academic abilities as well as those typically using learning approaches ranging from deep to surface, as identified by the Learning Approach Questionnaire (modified from Entwistle & Ramsden's [1983] instrument) and their teacher's evaluation of their school work. Other selection criteria included: good attendance, being verbally expressive and on-task, having at least average success in science, and having the ability to work well with each other.

The science class was observed for nine weeks during the instruction of a chemistry unit. The six students worked in two same-sex groups of three during their class activities. The boys' group consisted of Rick, Quin, and Carl while the girls' group comprised Mary, Bess, and Dale. Rick and Mary were identified as learners who used a predominantly deep learning approach, Carl and Dale as learners who typically used a more surface approach, while Quin and Bess used an approach that lay somewhere between a deep and surface approach. The topics covered in the chemistry unit included the nature of matter (elements, mixtures, compounds, atoms and molecules), states of matter and changes of state, physical and chemical changes, acids and bases. The hands-on laboratory activities for which students worked in small groups are included the following:

- *Separation of Salt-sand Mixture.* This was an open-ended problem-solving activity where the students had to devise a method for separating a mixture of salt and sand.
- *Boiling Point Lab.* The students had to plot and compare the temperature graphs for plain water and salt water when ice and salted ice were heated until boiling.

- *Chromatography.* The students used paper chromatography to separate the dyes in the ink from different coloured marker pens and calculated the retention factor (R_f) for each dye.
- *Chemical Change: Reaction Between Zinc and Dilute Hydrochloric Acid.* The teacher gave a demonstration on how to carry out the activity. The students then performed the activity individually in their groups.
- *Acids and Bases.* The students were required to determine if some common household substances (vinegar, baking soda, water, salt water, ammonia, aspirin, antacid tablets, alcohol, bleach, coca-cola, coffee, mouthwash, and lemon juice) were acidic, basic, or neutral using cabbage juice and blueberry juice as indicators.

Except for the first activity on the separation of a salt-sand mixture, the students were given verbal procedures for the other activities.

The boys were audiotaped and the girls were videotaped during the science hands-on activities, and were encouraged to think aloud and to verbalise their thoughts. Field notes were taken. The students were also interviewed individually after instruction of the chemistry unit to find out more about their understanding of the science concepts in this unit. The interviews were audiotaped. Stimulated recall was used to obtain further information about how the students tackled the tasks and what they were thinking of while engaged in the laboratory activities. This provided information about silent thoughts which were not always verbalised and captured on tape.

To find out if the students had other questions that were not verbalised during the activities and thus not captured on tape, the students were asked to write down any questions they had at home, as part of a learning journal, particularly about things that puzzled them. For the boiling point activity, the teacher also set aside time during the lesson for the students in class to write down questions. During the post-instructional interviews, the students were also asked if they had any questions pertaining to the hands-on activities.

Data from multiple sources (field notes, transcripts of classroom discourse from the audiotapes and videotapes, audiotaped interviews with the students, and students' written work) were analysed in relation to each other; this served to triangulate the data and to help enhance the credibility of the findings and assertions made (Lincoln and Guba 1985, Stake 1995). The target students' taped interviews and discourse during class activities were transcribed verbatim and subsequently analysed. Transcribed discourse from the videotapes was also supplemented with descriptive notes obtained by viewing the videotapes to obtain information about what the students did during the laboratory activities.

To identify the types of questions that students asked, the transcripts were read through several times. Coding categories (Bogdan and Biklen 1992) were then developed by making annotated descriptive and interpretive comments in the margins of the transcripts each time a question was documented. These became the tentative coding categories. Subsequent transcript segments containing questions were then annotated with the appropriate code. A constant comparative method (Glaser and Strauss 1967) was used to cluster the codes into progressively more inclusive categories forming a hierarchical taxonomy or working typologies. Frequency counts of these various types of questions that the students asked while carrying out the activities were also computed. Subsequent segments of the transcript following the questions were scrutinised to study the evolution and

progress of students' thinking and actions during their knowledge construction process. Assertions were made based on patterns observed which were grounded in the data.

Results

Types of Questions

Two broad types of questions may be distinguished; basic information questions and wonderment questions (c.f., Scardamalia and Bereiter, 1992). Basic information questions comprised factual and procedural questions. Factual questions usually required only recall of information, were often closed questions, and typically related to information in the textbook or some simple observation made about an event, such as 'What does the dictionary say about salt?'. Procedural questions sought clarification about a given procedure or asked how a task was to be carried out. They were asked particularly when step-by-step instructions had been given. Examples include 'Did she [teacher] say to put it in a pan?'.

Wonderment questions, which were pitched at a conceptually higher level, included (a) comprehension questions which typically sought an explanation of something not understood, (b) prediction questions of the 'What would happen if ...' variety involving some speculation or hypothesis-verification, (c) anomaly detection questions where the student expressed scepticism or detected some discrepant information or cognitive conflict, and sought to address this anomalous data, (d) application questions in which the student wondered of what use was the information that he or she was dealing with, and (e) planning or strategy questions where the student was temporarily stuck and wondered how best to proceed next when no prior procedure had been given.

Table 1 shows the relative frequencies of the different types of questions that the six students asked during the hands-on activities.

Table 1
Types and Frequencies of Questions Asked by Students During Hands-on Activities

	Types of Questions			
Activity	Basic	Wonderment	Total	% Wonderment
Separation of Salt-sand Mixture	40	17	57	30
Boiling Point Lab	61	7	68	10
Chromatography	32	4	36	11
Acids and Bases	52	1	53	2
Zinc-HCl Chemical Reaction	5	1	6	17
Total	190[a]	30[b]	220	14

Note.
[a]Of the 190 basic information questions, 48 were factual and 142 were procedural.
[b]Of the 30 wonderment questions 15 were comprehension questions.

Most of the questions that the students asked during the hands-on activities were generally not of a conceptually high level that were manifestations of deep thinking. Wonderment questions comprised only 14% of all the questions asked, and half of the wonderment questions were comprehension questions which focused on explanations. In contrast, 65% of the questions were procedural ones. The open-ended problem-solving activity on separating a salt-sand mixture elicited more and a wider range of wonderment questions than teacher-directed activities such as the one on zinc-hydrochloric acid chemical reaction which was carried out more in the form of an illustration or a verification rather than in the spirit of inquiry.

The number and types of questions asked by the individual students are summarised in table 2.

Table 2
Questions Asked by Individual Students During Hands-on Activities

	Types of Questions			
Student	Basic	Wonderment	Total	% Wonderment
Boys				
Rick	24	6	30	20
Quin	30	8	38	21
Carl	31	1	32	3
Girls				
Mary	47	4	51	8
Bess	42	10	52	19
Dale	16	1	17	6
Total	190	30	220	14

The wonderment questions were asked mainly by Bess, Quin, Rick, and Mary. Wonderment questions comprised an average of 20% of all the questions that Rick, Quin, and Bess asked. That is, they each asked about four basic information questions to every one wonderment question. In contrast, the percentage of wonderment to total questions asked was relatively low for Carl (3%) and Dale (6%). Even Mary, who often used deep learning strategies such as creating analogies, hypothesising, predicting, generating explanations, invoking personal experiences and applying prior knowledge to new situations asked comparatively few wonderment questions (8%). Interestingly, Good, Slavings, Harel, and Emerson (1987) found that average achievers (cf. Bess and Quin) asked more questions than low and high achievers.

Basic Information Questions

Basic information questions were typically either ignored or simply responded to with a short, simple answer without leading to further conceptual talk. Consider the following segment from the activity on acids or bases. Most of the talk was procedural and involved recording colour changes and noting the number of drops of solution added.

Carl: *How many drops [of cabbage juice indicator] did you put in?*
Quin: … 6, 7 … [ignoring Carl and counting the number of drops to himself]
Carl: 30?
Quin: … 9, 10, 11, 12, 13, 14 …. Almost done. *And what are we supposed to do next?*
Carl: Add some stuff that Rick is getting …. Put them in till it changes colour….
(Rick added aspirin to one of the test tubes.)
Rick: This is aspirin…. Well, there it goes. It's changing colour.
Carl: It's purple…. *How many did you put in*?….
Rick: Five drops.

The students then tested ammonia solution, coca-cola, mouthwash, bleach, alcohol, lemon juice, baking soda, and water with the cabbage juice indicator. The author [CC], who observed the lessons, then asked the boys what sense they were making out of their observations.

CC: Why do you think the solutions are changing colour?
Quin: I don't know … chemicals mixing.
Carl: The different chemicals, they are just reacting.

The above excerpt shows that basic information (factual and procedural) questions had little effect on students' subsequent cognitive behaviours, and engendered little productive discourse. The students were merely following the teacher's instructions without understanding much of what was happening, and were thus unable to explain why the solutions changed colours.

Wonderment Questions

Unlike basic information questions, wonderment questions tended to elicit responses that were of a more conceptual nature. Examples of students' questions are given, together with an analysis of the responses elicited.

Separation of Salt-sand Mixture. Quin first asked a prediction question 'How about we pour some water in here?' that was of a speculative nature as he did not know what exactly was going to happen then. After some discussion, the students poured water into the beaker containing the salt-sand mixture and stirred it with a spoon. Quin asked the comprehension question, 'What do you all think the water is going to do?' as he was still unsure of the purpose of adding water. What followed was interesting because he answered his own question by offering the explanation 'I think water absorbed the salt', and Carl elaborated on this by saying, 'The dirt [sand] didn't dissolve, so the dirt separated…. The salt dissolved. It's in there'. As the dissolved salt was no more perceptible, Rick asked Carl an anomaly detection question 'How do you know it's in there?'. He wanted Carl to provide evidence for this and said, 'Take a test'.

After draining the salt solution from the wet sand, Quin noticed that there was no more salt mixed with the sand. This prompted him to ask another comprehension question 'A lot of sand, but where did the salt go?' as he tried to figure out what had happened to the salt. Quin wondered how he could recover the salt from the salt solution and further posed a planning or strategy question 'How are we going to bring it back?'. The boys were stuck for a while. What followed was interesting because Quin's question stimulated Rick to think of the possibility of heating the salt solution. Here is an example where a student's (Rick's)

deep thinking processes were triggered off by a peer's question, and shows the effect of social interaction on stimulating the student's use of strategies which had hitherto, been perhaps latent. Finally, the boys managed to recover the salt by heating the salt solution over the alcohol burner.

When Rick asked Quin what he was thinking of when the salt soluion was being heated, Quin said that he was trying to 'melt' the water, Carl corrected him by suggesting that 'evaporate' was a more appropriate word as the water was 'boiling'. And Rick demonstrated uptake of this information by adding that 'the salt will stay there'. There was co-construction of knowledge during the group interaction when the boys refined each other's ideas. The above example shows the potentially powerful effect of wonderment questions in stimulating further thinking in the questioner himself (viz. Quin) and those who were engaged in conversation with him (viz. Rick). These questions, which arose because of the students' speculation or puzzlement, served to direct further inquiry and elicit explanations of what was going on.

The girls tried to use a magnet, a sifter, and to create static electricity, all without success. Then Bess asked a series of questions which stimulated Mary to think of ideas that led her to a 'breakthrough,' a moment of insight, where she finally solved the problem by adding water to the salt-sand mixture, decanting the salt solution from the wet sand, and then heating the salt water with an alcohol burner to evaporate the water and recover the salt.

Bess: Sand [...] sand is on a beach, right?
Mary: Beaches are warm.
Bess: And you know what else? Salt water comes onto beaches. *How does the salt stay there?*
Mary: OK, we are going to go back to the fire theory!

During the post-instructional interview, Mary explained what she was thinking of at that moment.

Mary: I was trying to think about the ocean and stuff.... And I was thinking about when I went to my grandma's house one summer [...] she has a beach-house on Myrtle beach which is in South Carolina. And where she lives, there's kind of like a cliff thing on the left of the house. And there's always like a thin film of salt that's on the rocks. And I was trying to think of how that salt had gotten there, extracted from the water. And [...] uh, finally it dawned on me, I was like whoa! [...] you know, the ocean's moving you know. It's warm, the sun's on it. You know, maybe that's how it got there. And then it just clicked at me. I was like wow! That's how you do it. So I poured the [salt] water in the thing [aluminium pan] and I heated it up.... That's why I thought of heating it. I was linking it to my grandma's house.

Mary had made a connection between the sand, salt, water, and heating in the current activity and the beach sand, salt on the rocks, ocean waters, and hot sun when she was at her grandmother's beach-house. And all this thinking was stimulated by Bess' comprehension question 'How does salt stay there?' when she was referring to the salt on beaches and trying to decipher how that came about. This is another example where one student's wonderment question stimulated another to figure out a solution to a problem. It shows the interaction of situational and social factors in bringing deep thinking strategies to surface in a student. In this case (as in the previous example with the boys' group), it was the average student (Bess

cf. Quin) who asked the wonderment question, but the academically more able student (Mary cf. Rick) who followed up on the question and came up with a solution to the problem.

Boiling Point Lab. Unlike the activity on separating the salt-sand mixture which was problem-solving in nature, the boiling point activity was relatively procedural and did not engender much conceptual talk, most of the statements made by the students were procedural and observational, and few wonderment questions were asked. Because the students were so engrossed in getting the tasks done in the time required, they did not ask many questions although some observations puzzled them. Even when a question was asked, there was little follow-up discussion as the students busied themselves with carrying out the prescribed procedures.

Data about students' questions from students' learning journals, the post-instructional interviews, and a class writing session where students wrote questions showed that the students did have more questions beyond those verbalised during the activity. Having to think about what had puzzled them and having to ask questions about the activity made the students more aware of what they did not understand or had not thought of earlier. Dale wanted to know 'Why [does] salt water get hotter?'. Bess was surprised to note the formation of bubbles at temperatures below 100 °C, and wanted to know 'Why did the water boil below the boiling point?'. Quin was puzzled about why the temperature stayed constant at the boiling point.

The case of Carl was particularly enlightening. Although he did not ask any wonderment questions during the activity itself, he had some interesting ideas when he wrote the questions in class and in his learning journal. He wrote 'I learnt the temperature is more extreme when you add salt' and 'It was amazing when water boiled below the boiling point'. His latter idea probably referred to the formation of bubbles below 100 °C. He also wrote 'I would like to experiment not only with salt but with sugar' and wondered 'if it would be different temperatures if we used an alcohol burner instead of a hot-plate'.

Because there was no whole-class discussion by the teacher after this laboratory activity, some concepts pertaining to the various related phenomena and the questions raised by the students were not addressed. The above findings suggest that students do not always ask wonderment questions spontaneously. Unless they are encouraged to ask them by deliberately incorporating question-asking in the lesson plan rather than leaving them to chance, many of the students' questions and puzzlement may go undetected and not be dealt with. Wonderment questions, unlike basic information questions, have great potential in stimulating conceptual talk at a higher cognitive level which help students address the major concepts involved in the activities. These questions could help direct further inquiry and trigger deeper thinking in students as they discuss their ideas and generate explanations for their observations.

Chromatography Activity. After the boys had spotted the different ink colours on the filter paper strips, they left the strips to stand. They had been engaged in conversation of a procedural nature and had not discussed anything about the separation of colours in the developing chromatograms. So the author [CC] decided to find out how they would interpret this observation.

CC: I notice the colours are spreading. There are different shades now....
Quin: *Where's the dot [initial ink spot]?*

Carl: The dots are gone! ....
CC: What do you think is happening? Why do the dots go away?
Rick: They travel in the water.
Quin: Water is travelling up the paper. It made the colour spread.
CC: Mrs. Jones was talking about the molecules. How do you think that actually happens?
Quin: The water attract the molecules.
Rick: They connect and then they move up with each other.
Quin: Move up. Gets to the top so it would attract all the others.

What was it that stimulated Quin to ask 'Where's the dot?' and Carl to notice with surprise, that the 'dots' had disappeared? Perhaps it was due to the author's prompting and pointing out to the boys that although there was originally only one colour, the chromatogram was beginning to show different colours. Furthermore, when the author asked the boys 'Why do the dots go away?', they attempted to explain what was happening to the colours. This episode suggests the importance and facilitative effects that scaffolding has on students asking questions.

In his learning journal, Rick wrote 'We found out what different colours had to be mixed to form one'. He wanted to know 'Why do they [ink spots] separate like that?' and 'What do these [R_f] numbers mean?'. Carl had three interesting wonderment questions. First, he wanted to know 'Why do some pen [ink] run faster than others?'. This question indicated that he was wondering why the component ink colours had travelled different distances along the filter paper strip. Second, he wanted to know 'Why did some change colours and others didn't?', as he was puzzled by why some of the component ink colours were of a similar colour to the original ink spot whereas others were different from the original one. The third question he asked was 'If you put more than one colour, would it separate into just more [colours]?'. He elaborated on this by saying:

> Say you have blue and it changes into pink and green. And then you have purple, and it changes into blue and yellow. If you take this colour, you put it right there, and you put this colour and you put it on top of it. Would you have those four colours that come out of it?

This last prediction question was like a thought experiment involving conjecture where Carl extended his ideas to a hypothetical situation in which he wondered what would happen if two ink colours were mixed together in the original spot. What was interesting about Carl was that he asked some thoughtful wonderment questions when he was specifically requested to ask questions after doing the activity. Among the girls, Dale had no further questions, Bess wanted to know what the R_f values meant, and Mary asked: 'What is the R_f used for?' (an application question).

These findings further reinforce the point that wonderment questions may not always be asked spontaneously by students, especially if the students are too preoccupied with following given procedures and not thinking deeply about what is going on during the activity. Most of the wonderment questions asked during the activities came from Quin, Rick, and Bess. The two students, Carl and Dale, who used a predominantly surface approach to learning hardly asked any wonderment questions while performing the activities. This is not surprising. However, what was unexpected was that when the students were specifically instructed to ask questions, Carl was able to come up with some meaningful wonderment questions. This suggests that even students who do not typically ask higher-

level wonderment questions spontaneously are capable of doing so if given the time and encouragement.

Discussion, Implications, and Conclusions

Question Types, Role in Knowledge Construction, and Relationship to Learning Approaches

There were two main categories of student-generated questions: basic information and wonderment questions. Basic information questions comprised factual and procedural questions. Wonderment questions which were pitched at a conceptually higher level included comprehension, prediction, anomaly detection, application, and planning or strategy questions. There were relatively few wonderment questions (14%) compared to the total number of questions asked. Procedural questions of a low-level nature constituted 65% of all students' questions. The problem-solving activity on separating a salt-sand mixture elicited a comparatively high percentage (30%) of wonderment questions. In contrast, where step-by-step instructions were given, the students were engrossed in following procedures and this resulted in far more procedural questions being asked.

Wonderment questions can facilitate knowledge construction by guiding thinking and promoting conceptual talk that pertain to the core concepts of an activity. It was found that such questions stimulated not only the students themselves, but also their group members to hypothesise, predict, seek and generate explanations for things which puzzled them. That is, these questions triggered the use of deep thinking strategies which may not be invoked if these questions had not been asked. The questions played an important role in engaging the students' minds more actively, engendering productive discussion, and leading to meaningful construction of knowledge both individually and collaboratively.

Questions are one of the psychological tools for thinking, and when embedded in the discourse of collaborative peer groups, help learners co-construct knowledge inter-psychologically. This knowledge is then appropriated or constructed intra-psychologically by the individual members (Vygotsky 1978). From a social-cognitive perspective, questioning in a group context can also encourage students to reconsider their ideas in new ways because they are exposed to different peer perspectives. An example from this study would be when Quin reconsidered his ideas of melting and evaporating in the activity on separating the salt-sand mixture. Question-generation is a constructive activity and is an essential component of student discourse in 'talking science' (Hawkins and Pea 1987, Lemke 1990) in the social construction of knowledge (Driver, Asoko, Leach, Mortimer, and Scott 1994).

The types of questions that students ask can reveal their depth of thinking. Wonderment questions are associated with a deep approach to learning whereas basic information questions are related to a more surface approach. However, asking wonderment questions is indicative of only one dimension of a deep learning approach, the other possible dimensions being generative thinking, nature of explanations, metacognitive activity, and approach to tasks (Chin and Brown 2000a). The two students who typically exhibited a surface learning approach asked relatively few wonderment questions. However, Mary, who typically used several other deep learning strategies did not ask many wonderment questions either. This finding seems consistent with the suggestion by Chin and Brown (2000a) that students can exhibit depth of thinking in different ways, and that there may be multiple dimensions associated with a deep learning approach.

One limitation of this study is that the findings were based on only six students from the same class taught by one teacher. Time and manpower limitations precluded the collection of additional data from other groups or classes to further confirm the categories of questions generated. The findings are thus presented as grounded hypotheses rather than generalisable findings. Another limitation is that some of the students' questions may not have been verbalised or thought-aloud during the hands-on activities, and thus were not captured on tape as verbal data for subsequent analysis. Although attempts were made to maximise the collection of data on students' questions (through stimulated recall during post-instructional interviews and written questions), it was not possible to document each and every question that the students had.

This study investigated the types of questions that students asked and identified some of the questions that students should be encouraged to ask to bring about deeper learning and meaningful knowledge construction. As this study focused on students' questions that arose naturally in discourse in authentic settings and the kinds of responses that the questions elicited, it provides information beyond that of previous research on students' questions where the concern was mainly on written questions, questions asked in response to reading a given text as part of an ad hoc task, or after training students to ask certain kinds of questions. The importance of this study also lies in the development of a taxonomy of question types which classifies students' questions according to different conceptual levels. Such a classification could be useful in helping teachers to plan their activities so as to foster student questioning at a higher cognitive level.

Emergent Issues and Implications of Students' Questions for Science Teaching

There are five important issues regarding questioning by students. First, asking wonderment questions is reflective of a deep learning approach. Thus, students should be encouraged to ask such questions and to 'enter the depth dynamic' (Chin and Brown 2000b) so as to increase their depth of thinking in other related areas. Second, students asked mainly procedural questions when the assigned tasks required them to follow given instructions and step-by-step procedures, and this did not engage them at high cognitive levels. In contrast, an open-ended, problem-solving activity carried out in the spirit of a scientific inquiry, elicited more and a richer range of wonderment questions and talk at higher conceptual levels. This implies that the nature of tasks that teachers set and the cognitive demands required of the students influence the types of questions that students ask, and thus to some extent, the learning approach and learning strategies that they adopt. Hence, to encourage deep thinking in their students, teachers should present their laboratory activities in a manner that encourages inquiry and problem-solving rather than following instructions to obtain an expected answer.

Third, asking wonderment questions can stimulate either the questioners themselves or another student to generate an answer, thereby bringing to the fore, other deep learning strategies which have hitherto been latent, and potentially leading to talk at a higher conceptual level. One implication arising from this pertains to the assignment of students in groups. A teacher might consider including at least one "inquisitive" student in a group to steer the other group members in their thinking and co-construction of knowledge.

Fourth, although the students did not always generate wonderment questions spontaneously, they asked more meaningful questions upon subsequent probing and nudging during the post-instructional interviews and when they were requested to write questions in their learning journals. This suggests that unless students are stimulated to think about such

questions, many students would not ask them. Consequently, a lot of potential conceptual talk could be untapped if these questions are not asked. Teachers cannot fully rely on students' spontaneous questioning and must explicitly orient their students towards asking questions, for example, by specifically encouraging them to generate questions, either verbally or written, as part of their class activities. Besides prompting students to think more deeply about what they are doing and encouraging critical thinking, such questions could also provide feedback to teachers about their students' thinking and puzzlement, and act as a window to the students' minds.

Fifth, even the students who typically did not spontaneously ask higher-level wonderment questions were capable of asking thoughtful questions when time was specifically set aside for them to ask questions about things that puzzled them or which they would like to know more about. This suggests that teachers could explicitly encourage such students to ask questions by providing extra opportunities for them to do so.

The results of this study indicate that student-generated questions are a meaningful aspect of learning in science. So how can teachers can encourage a 'question-based learning' approach (Watts, Gould, and Alsop 1997) in their classrooms? Teachers could ask students to write their questions before performing an activity to help them direct their own inquiry and use these questions as a springboard for investigation and discussion. The students could also write questions as they work on their tasks and at the end of the activity, regarding what had puzzled them, or what they want to know more about.

Biddulph, Symington, and Osborne (1986) suggested four ways of encouraging students to ask questions.. These include providing students with suitable stimuli, modelling question-asking, developing a receptive classroom atmosphere, and including question-asking in evaluation. White and Gunstone (1992) proposed the use of a stimulus (e.g. table of data or diagram) on which questions are to be based, providing an answer and asking for questions, and asking students to begin questions in a particular way (e.g. 'What if ...', 'Why does...', 'Why are ...', 'How would ...') as such questions are more likely to be based on deeper thinking than simple recall. King (1994) found that giving students thought-provoking question stems helped them to generate questions that prompted them to compare and contrast, infer cause and effect, note strengths and weaknesses, evaluate ideas, explain, and justify. Students can also be guided to form investigible questions that are amenable to practical investigations. Such questions have been termed 'productive' questions (Elstgeest 1985) or 'operational' questions (Alfke 1974, Allison and Shrigley 1986). Operational questions help students to manipulate variables in science experiments through eliminating, substituting, and increasing or decreasing the presence of a variable.

Teachers can also ask their students to record any questions that they have in a diary or learning journal, thus documenting a set of 'I Wonder' questions (e.g. Kulas 1995). The teacher can pause at convenient intervals during the lesson and request the students to write down questions they wish to ask, and then use these questions as 'thought provokers' for stimulating discussions (Maskill and Pedrosa de Jesus 1997). Watts, Gould, and Alsop (1997) have also suggested including specific times for questions such as a period of 'free question time' within a lesson or block of lessons, a question 'brainstorm' at the start of a topic, a 'question box' on a side table where students can put their (anonymous) questions, turn-taking questioning around the class where each student or group of students must prepare a question to be asked of others, and 'question-making' homework. Teachers can

also establish a 'problem corner' in the classroom and encourage students to supply 'questions of the week' (Jelly 1985).

There is much scope for future research on how innovative pedagogies can be best implemented in the classroom to realise Shodell's (1995) vision of the 'question-driven classroom' where each student is placed in an active role as questioner, to promote inquiry in science instruction. It is widely agreed among the educational community that to know how to question is critical to knowing how to teach well. However, with the emphasis today on active, independent, and student-centred learning, to know how to question is also to know how to learn well.

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Organization/Address: National Institute of Education Nanyang Technological University 1 Nanyang Walk SINGAPORE 637616	Telephone: (65)-790-3853	FAX: (65) 896-9414
	E-Mail Address: hlcchin@nie.edu.sg	Date: 11 April 2001

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